COMPARATIVE COSTS OF ELECTRICITY GENERATION: A CANADIAN PERSPECTIVE

Brian Moore, Sylvana Guindon
Natural Resources Canada, Canada

ABSTRACT

This paper examines the levelized unit energy cost (LUEC) approach in comparing the relative economics of various forms of generating electricity; discusses the key factors impacting on the costs of nuclear, coal and gas-fired electricity and presents results from recent international and Canadian LUEC studies.

ELECTRICITY PRODUCTION IN CANADA

Total electricity generation in Canada was 547.8 TW.h in 1996, with over 60% supplied from hydro, 16 percent from nuclear and 20 percent from fossil fuels, primarily coal. Domestic electricity demand is projected to grow at an average annual rate of 1.0 percent for the next twenty five years, a much lower rate than the 2.6 percent annual growth rate witnessed during the last fifteen years. Significant excess generating capacity currently exists in all regions of the country, leading to a situation where no additional baseload generating capacity is likely to be required until about the year 2010.

Canada’s electric power industry is currently dominated by provincial Crown-owned utilities operating in a highly regulated market. However, as in many other jurisdictions, the industry is entering a period of fundamental change toward a more competitive, deregulated market. Many provinces are moving towards, or considering, deregulation and/or privatisation of electric power utilities. The restructuring of electricity markets is expected to lead to a lowering of retail electricity prices over time, thereby increasing competitive pressures on generators to produce electricity at the lowest possible cost. Thus, when new capacity is required, average production costs per unit will be a significant investment criteria.

THE LEVELIZED UNIT ENERGY COST (LUEC) METHODOLOGY

The Levelized Unit Energy Cost (LUEC) approach to the comparative analysis of the economics of various generating options focusses on the discounted life-cycle average cost per unit of electricity produced taking into account all capital and operating costs. This all-in unit cost of producing electricity over the life of a power plant can then be compared as one important measure of the relative attractiveness of each investment option.

Capital, operating and maintenance (O&M) and fuel costs vary widely for different generating options and technologies. Costs can also vary from station to station, from design to design and from year to year for a given option. There are different ranges in technical and economic assumptions (eg. plant life, capacity utilization factors) for different types of plants. LUEC adopts common assumptions for the main technical and economic parameters in order to provide a consistent framework for comparing the cost of electricity from different energy sources and different technologies.

LUEC is defined as the discounted average cost of producing electricity from a power plant and is expressed in terms of cents or mills per kWh. It takes into account the total discounted cost of producing the energy (capital, operating and maintenance and fuel costs) and the total amount of energy produced over the life of the plant, and distributes these costs over the anticipated operating life of the station. Using LUEC, one can calculate generating costs over the expected operating lives of new baseload power plants using either established or new technologies. LUEC is also helpful in analysing major capital investments in existing plants to determine whether the plants are financially amenable to refurbishment and life extension.

While the LUEC approach is extremely useful for comparing various investment options, utilities do not make planning decisions solely on the basis of average unit production costs. LUEC provides only part of the information a utility needs in determining the optimum generating option(s). The utility must do a complete study of its options and the markets in which it operates including, supply-demand balances, price outlooks for fuels, potential timing and impacts of technology improvements, rates of return, payout periods and other factors. Most recently, greenhouse gas emission reduction obligations under the Kyoto Protocol may constrain future electricity generation choices.

International studies provide an indication of the relative economics of the various generating options within and between countries. However, caution is advised in the application of LUEC in assessing different technologies and in comparing costs between regions and countries because of fluctuating exchange rates and of variations in design and site requirements, capital, fuel and O&M costs. As well, there are differences in regulatory and legislative frameworks, infrastructure and site specific conditions, economic assumptions such as material and labour costs, and policies, such as those relating to fuel management, etc. The most meaningful comparison is one in which specific plant types meeting the requirements of a country or region are costed in that particular country or region on a common basis.

LUEC AND DIFFERENT GENERATING SOURCES

The LUEC methodology enables one to vary capacity factors, operating lives, interest (or discount) rates and other key factors to assess the impact of different assumptions on costs. Changes in fuel, capital and O&M costs also have varying effects on unit costs for different generating options.

Hydro and nuclear electricity costs are dominated by capital costs and are very sensitive to the time taken for plant construction, interest rates on borrowed funds, explicit or implicit return on equity, changes to the regulatory regime, and price changes for equipment, material and labour during the construction period. The high up-front capital costs result in greater investment risk if there are construction delays or cost overruns. The high up-front capital cost of hydro and nuclear plants is counter-balanced by the low fuel and water rental costs.

To be economic, nuclear plants must have increasingly larger capacities, which increase capital requirements, and therefore financial exposure. During periods of low or uncertain load growth, the financial risk may be too substantial to order a large, high cost plant that will only come into service in six to ten years. (Capital or investment costs include pre-construction, overnight construction, actuarial provisions for major refurbishment and decommissioning and, in the case of nuclear, the cost of spent fuel management and disposal.)

Once built, nuclear plants are in principle relatively immune to inflationary pressures, but their cost efficiency over a 30 or 40 year lifetime will depend on their capacity utilization factor. A high level of power output is needed to provide adequate returns on investment. It is for this reason that the nuclear option is particularly suited to meeting base load demand. In many countries the performance record of nuclear power plants has been generally improving. Nonetheless, any lengthy shutdown, with attendant high-cost repairs, particularly if it occurs early in a plant's life, exposes reactor owners to financial exposure not faced by owners of low capital cost stations.

Coal and gas-fired plants, which are less expensive to build, carry a higher risk on variable operating costs, such as fuel prices and availability of fuel. In this regard, it is interesting to note that the LUEC data supplied by Canada for the 1997 Nuclear Energy Agency/International Energy Agency (NEA/IEA)

Generation Cost Study shows that fuel costs represent over 68% of the total LUEC for the combined cycle gas station while capital cost represents only 25% of the LUEC. On the other hand, for the nuclear stations, fuel cost represents about 9% of the total LUEC while capital costs represent about 66% of the total.

All types of plants are facing increasingly stringent regulatory and environmental controls. Efforts are underway in various for a to find ways of internalizing the costs of many impacts that were previously considered external. The nuclear industry believes that it has largely internalized its safety, environmental and waste management costs and that this internalization is reflected primarily in the relatively high capital costs for the stations.

On the other hand, emissions of greenhouse and sulphurous gases have not been internalized as a LUEC cost although they are significant. NRCan studies show that in 1996, nuclear energy reduced electric utility emissions in Canada by about 50%. In other words, emissions were about 50% lower than they would have been if fossil fuels had been used instead of nuclear generation in 1996. Table 1 summarizes the impact of nuclear generation on

Table 1 Emissions Avoided From the Use of Nuclear Energy in 1996

Emission Type	Actual Electricity Sector Emissions (tonnes)	Emissions Avoided by Nuclear Plants (tonnes)	Emissions Reduction in the Electricity Sector (%)
CO2	91,552,000	81,900,000	47%
NOX	205,000	222,200	52%
VOC	1,774	1,497	46%
CH4	757	526	41%
SO2	497,000	491,200	49%

Canadian emissions from the electric power sector 1996. Over the period 1971-96, electricity generated by Canada's nuclear plants have avoided 1,222 million tonnes of carbon dioxide emissions alone. The impact on comparative costs of these emissions merits further study and the LUEC approach could be a useful tool for this type of analysis. The impact of these costs on LUEC are not discussed in this paper, nor are external costs associated with the construction of hydro plants. Limitations and levies on air emissions could render coal and gas-fired generation considerably more expensive.

STUDIES USING LUEC

Canadian utilities, the Canadian National Energy Board (NEB) and Natural Resources Canada (NRCan) make use of LUEC, as do international energy organizations such as the Nuclear Energy Agency (NEA) of the OECD and the International Energy Agency (IEA). We focus on the results of recent LUEC studies by NRCan and the NEA/IEA. The studies differ in their assumptions, their scope, their purpose, the time at which they were done and the timing of the projects they consider. Consequently, they give somewhat different results. Nonetheless, some fundamental common trends emerge from these studies.

NRCan's specific interest in using the methodology is to better understand the factors impacting on costs of baseload generation options available in Canada in the medium term.

NRCan's most recent study, undertaken in the mid-1990's, used as the reference case an in-service date of 2000, a 75% capacity factor (except for hydro plants), a 30 year life (except for hydro plants) and a 5% real discount rate. NRCan uses its model to:

(1) run Canadian utility data submitted to the NEA/IEA;

(2) run reference cases using NRCan fuel price projections (for gas, coal, nuclear and hydro plants as well as renewable sources of energy).
(3) run sensitivities to determine the impact on all plants of changes to discount rates, capital costs, capacity factor, fuel price and operating life.
(4) assess the comparative costs of refurbishment.

The 1997 NEA/IEA study, is the fifth of a series completed roughly every three years beginning in 1983. In the 1997 study (not as yet published), the NEA/IEA used data provided in 1997 by 16 OECD and 5 non-OECD countries. It focuses on baseload nuclear, fossil, renewable plants and new technologies pertaining to all fuel types; hydro is not considered as its costs tend to be site-specific.

There are cost differences between regions and countries with respect to capital, O&M and fuel cost inputs. The studies require participants to use some common economic and technical variables for all types of stations; the 1997 study required participants to provide cost data for a 75% capacity factor, 5 and 10% real discount rates and a 40 year operating life.

RESULTS OF THE STUDIES

Natural Resources Canada: The NRCan study results at the 5% and 10% real discount rates for gas, coal, nuclear and hydro show that:

- There are strong regional differences in Canada. Fossil-fired generation in western Canada, for instance, have the lowest LUECs.
- At the 5% real discount rate, LUEC was lower for nuclear than for coal and natural gas in Central Canada; the ratio of nuclear to coal is about 0.80. Nuclear power loses its advantage over coal at the 10% real discount rate.
- In Central Canada, the LUEC for a gas-fired plant was significantly higher than coal and nuclear at both the 5% and 10% real discount rates.
- Nuclear energy is a competitive baseload source of electricity in regions of Canada without immediate access to low-cost fossil fuels and large base-load hydro resources.

It is anticipated that the results of current studies, to be completed by the spring of 1998, will show a significant reduction in the LUEC for natural gas in Central Canada.

Table 2 presents LUEC data for three different technologies (nuclear (CANDU 6 and 9), natural gas (combined cycle gas turbine or CCGT) and coal which was presented to the NEA/IEA for the 1997 Generation Cost Study. It is assumed that both fossil stations would be located in Central Canada.

Table 2 LUEC at the 5% Real Discount Rate (CDN mills/kWh)

Unit	O&M	Fuel	Investment	LUEC
CANDU 9 (2x881 MWe)	8.1	3.1	23	34.2
CANDU 6 (2x665 MWe)	11.4	3.3	25.1	39.8
CC Gas Turbine (2x750 MWe)	2.7	30.5	11.2	44.4
Coal (4x750 MWe)	5.4	23.9	13.8	43.1

Sensitivities were run to determine the impact of increases and decreases in capital cost, high and low capacity factors, fuel cost increases and decreases and different economic lives for plants. Nuclear and hydro were more sensitive to capital cost increases, discount rates, capacity factor and plant life than coal or gas, which are more sensitive to the cost of fuel. Lifetime extension impacts more heavily on the capital intensive nuclear plants. Capital cost decreases have a greater impact on LUEC than a lifetime extension for nuclear for a given plant, although in the comparison between existing and new plants, a life extension for an existing plant is generally more economic.

An economic evaluation using the LUEC approach for re-investing in the power plants at Pickering A and Bruce A was undertaken by Ernst and Young for Ontario Hydro; the results of evaluation were presented to the 1997 Ontario Select Committee on Ontario Hydro Nuclear Affairs. In the study, natural gas combined cycle plant was assumed to be the long-run price setter for base-load generation and was the only other option used for the comparative analysis. The study shows that while refurbishment costs are high, (783$ M CDN for Pickering A, 2741$ M CDN for 4 units at Bruce A, and 878$ M CDN for units 3 and 4 at Bruce A), on a LUEC basis electricity costs from rehabilitated Pickering A and Bruce A units is competitive. However, poor performance of the units, lower than anticipated price for gas and/or higher than anticipated efficiencies for gas units could affect the LUEC for Bruce A which requires higher up-front infusion of capital.

NEA/IEA Study: The NEA/IEA's update to the 1992 Generation Cost Study has not as yet been published but it is expected that it will be available by April of 1998. We want to highlight a few key findings of the NEA/IEA work which are consistent with Canadian results.

The price of fuel is the key determining factor for coal-fired and gas-fired LUEC. Coal prices are expected to be in the $1.00 - $3.20 (U.S.) per GJ range in the year 2005 in OECD and non-OECD countries; the average real price escalation rate is estimated to be 0.3 per cent per annum. Delivered gas costs in the year 2005 are expected to be in the $1.60 US to $5.35 $US/Gjoule range and average real gas prices are expected to increase at about 1% annually over the plant life. [NOTE: these price estimates were produced before the Kyoto Protocol which could impact on estimates.] In the 1992 study gas cost was $3.50 to $4.50 per GJ range for Central Canada and in other industrial countries; prices in western Canada are much lower.

In OECD countries, the construction cost of nuclear plants is in the 1,500$ to 2,500 $US per kilowatt (kWe) while that for coal is in the 1,000$ to 1350$ US per kWe range. Natural gas capital costs are much lower (below 800$ US per kWe in most OECD and non-OECD countries). Nuclear costs are much more sensitive to the discount rate, capacity utilisation factor and economic life than coal or gas-fired plants.

The NEA/IEA study results show that the estimated real nuclear LUECs for plants to be in service about ten years down the road from the time of the study remain fairly steady for most countries. Coal-fired electricity continues to be competitive because of low coal prices. Gas-fired LUECs have declined since the last study due to decreases in the estimated cost of natural gas, making gas-fired generation increasingly competitive. As compared to past studies, the ratios between cost estimates show the increasing competitiveness of gas-fired power plants versus coal and nuclear plants. Natural gas LUECs are more competitive in regions or countries with access to large, low-cost natural gas supplies. Natural gas is an attractive near-term option because of low cost, simple construction, maintenance, low fuel cost projections and low environmental emissions relative to coal.

At the 5 and 10% real discount rates, three countries, France, Japan and Korea, and Central Canada project generating costs lower for nuclear than for gas-fired plants.

CANDU LUEC (see Table 2) show that (ii) a CANDU 6 and a CANDU 9 are more economic than coal and gas in Central Canada at the 5% discount rate but not at the 10% real discount rate (the LUEC for

CANDU 6 is 28.2 mills US/kWh and a CANDU 9 23.5 (US) mills per kWh while the LUEC for a coal plant is 31.6 mills/kWh and for gas 32.5 mills kWh at the 5% real discount rate.) The nuclear/coal ratio is 0.89 for a CANDU 6 and .75 for a CANDU 9 and; (ii)while the data must be used with caution, the LUEC for the CANDU 6 and the 9 are among the lowest in the OECD countries. This is due primarily to the lower fuel costs (no enrichment needed and on-line fuelling). Electricity costs in Canada, particularly gas-fired generation in western Canada, are among the lowest in the OECD countries.)

To summarize, while results are different when different assumptions are used, there is consistency in the overall relative costs of the various options. In Canada, as in other parts of the world, no one fuel will be able to satisfy demands in all regions and under all circumstances. Nuclear power remains competitive with coal and gas-fired generation in certain regions of Canada and of the world but this competitiveness has been eroded in recent years by the low cost of fossil fuels.

OUTLOOK, UNCERTAINTY AND EXTERNALITIES

What can these studies of LUEC tell us about future prospects for the nuclear industry in Canada and around the world?

Economic studies show that nuclear energy is holding its own in terms of absolute costs. Increases in some cost components, such as O&M and refurbishment costs, are offset by decreases in other areas such as fuel costs. Nuclear is still competitive in some regions at low discount rates. Anything that can be done to lower the impact of interest rates, such as fast construction times and low real interest rates themselves, increase the relative attractiveness of the nuclear option.

However, coal and especially natural gas fired generation are becoming much more competitive. In the case of coal this is largely due to the reduced cost of the fuel itself. In the case of natural gas, it is due to a combination of reductions in the cost of natural gas and of the escalation rate for those costs, and also to the lower cost and improved efficiency of the technology for generating electricity from gas, along with heat in some cases.

Comparing historical LUEC estimates with experience in the real world, one notes some disparities. For instance, the assumed uninterrupted operating life has not materialized for all reactors in many countries, including Canada. When capacity factors for the Ontario Hydro stations were high in the late 1970's and early-to-mid-80's, nuclear costs were significantly less than fossil stations. This advantage faded in the late 1980's when plants had to be repaired, capacity factors fell, and fossil fuel prices dropped. The Ontario Hydro decision of August, 1997 has shown that:(1)nuclear assets need to be maintained in order to ensure good performance and good return on the investment; (2)the cost of maintaining nuclear assets is high when one looks at the immediate impact on balance sheet although on an LUEC basis nuclear is still competitive; (3)one needs to balance this high cost against emissions from fossil plants.

In Ontario, there were also significant capital cost overruns which impacted on the average cost of Darlington electricity and rates charged to consumers. At the same time, the CANDU 6 units in Quebec, New Brunswick, Korea, Argentina and Romania, some of which have been operating for close to 15 years, have had very good capacity factors, and, consequently, low energy unit production costs.

There are other limitations to the LUEC methodology in its inability to take into account the full costs and benefits of the options, many of which are difficult to quantify and estimate on a per kilowatt hour basis. The following costs are not included: infrastructure costs (e.g., R&D), broader macroeconomic factors such as indirect impact on employment and, as previously noted, environmental externalities, such the contribution to climate change from the burning of fossil fuels. Many utilities in North America and in countries of the OECD and international bodies, have begun integrating these costs to arrive at the least cost mix of resources within a sustainable development framework.

CONCLUSIONS

The cost of generating electricity will be even more critical factor in the decision-making process for electric power utilities in the years ahead as plans for new capacity are made under the pressures of a more competitive, deregulated market. Technologies with low capital, fuel and operating costs, short construction schedules, capacity closely matched to load growth and minimal regulatory/public acceptance problems are generally more attractive.

As the LUEC studies show, natural gas plants require ready access to low-cost supply of natural gas in order to compete. In areas with access to large supplies of low cost natural gas, it is therefore quite likely that natural gas turbines will be chosen, perhaps in combined cycles, for the next round of capacity increases in order to minimize financial risks. Gas turbine plants are relatively quick to build, have a low capital cost and high thermal efficiency and can be written off over shorter periods of time. There is now a general expectation that natural gas's contribution to electricity supplies will increase in Canada and other OECD countries.

While natural gas plants are attractive, access to the fuel, the potential escalation of natural gas market prices due to geopolitical and other events, the release of methane into the atmosphere during extraction and transmission are additional factors to consider. Even though it is too early to evaluate the impact of the Kyoto Protocol, it is possible that it will drive up natural gas as well as coal LUECs.

From a cost perspective, the challenge for the nuclear industry in Canada is to ensure, in the short to medium term, that the existing plants reach their full operating life and that they operate consistently at high capacity factors. In the longer term, improvements which lower the capital costs of nuclear plants, decrease construction times and increase capacity utilisation factors will enhance the competitiveness of the nuclear option.

REFERENCES

Department of Natural Resources, *“Comparative Cost of Electricity Generation”*, Ottawa, April, 1993

Department of Natural Resources, “Impact of Nuclear Energy on Canadian Electric Utility Fuel Use and Atmospheric Emissions: 1971-1996", Ottawa, December, 1997.

National Energy Board, “Comparative Costs of Generation in North America”, January, 1992.

OECD Nuclear Energy Agency/International Energy Agency, “Projected Costs of Generating Electricity: Update 1992”; “Projected Costs of Generating Electricity: Update 1997".

Ontario Hydro, “Submission to the Ontario Select Committee on Ontario Hydro Nuclear Affairs”, October 31, 1997.